QC1 T68
no. 67

UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES

No. 67: THE PERMEABILITY OF BALLOON FABRICS TO HYDROGEN AND TO HELIUM, BY R. T. ELWORTHY AND V. F. MURRAY

REPRINTED FROM TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA, SERIES III, VOL. XIII)

THE UNIVERSITY LIBRARY: PUBLISHED BY
THE LIBRARIAN, 1920

University of Toronto Studies
COMMITTEE OF MANAGEMENT

Chairman: SIR ROBERT ALEXANDER FALCONER, LL.D., K.C.M.G.
President of the University

PROFESSOR W. J. ALEXANDER, PH.D.
PROFESSOR J. J. MACKENZIE, B.A., M.B.
PROFESSOR J. P. MCMURRICH, PH.D.
BRIG.-GEN. C. H. MITCHELL, B.A.SC., C.B., C.M.G., D.S.O.
PROFESSOR G. H. NEEDLER, PH.D.
PROFESSOR GEORGE M. WRONG, M.A.

General Editor: H. H. LANGTON, M.A.
Librarian of the University

The Permeability of Balloon Fabrics to Hydrogen and to Helium [1]

By R. T. ELWORTHY, B.Sc., and V. F. MURRAY, M.A., B.Sc.

Presented by PROFESSOR J. C. MCLENNAN, F.R.S.

(Read May Meeting, 1919.)

INTRODUCTION

In view of the proposed use of helium in place of hydrogen for filling airship envelopes, it became necessary to investigate the permeability of fabrics to this gas; and more especially to obtain the ratio of the permeabilities to helium and to hydrogen of typical airship fabrics.

If it be assumed that the phenomenon of leakage through a fabric can be classified as effusion, a leakage of helium 0·71 times by volume that of hydrogen would be expected. If this ratio be calculated by the Hugoniot-Reynolds formula for the adiabatic efflux of a monatomic and a diatomic gas a value 0·75 is obtained.

The passage of a gas through a rubbered or a skin-lined fabric is not, however, a case of simple effusion, but is a more complex phenomenon. The solubility of the gas in the material may be a factor of importance[2].

Recently, Dewar[3] repeated the classical work of Graham on the diffusion of gases through rubber membranes. Gases at varying pressures and temperatures were allowed to diffuse through Para rubber membranes 0·01 mm. thick into a vacuum. Relative rates of diffusion were determined and are given in this paper as well as absolute rates expressed in cubic centimetre per day per square centimetre. Dewar found that the relative rates differed for different temperatures and he states that "the order of diffusibility is difficult to associate with any chemical or physical property." From his data the ratio of the diffusibility of helium to that of hydrogen is 0·43 at 15·5°C.

---

[1] Communicated by Professor J. C. McLennan, F.R.S., by permission of the Admiralty.

[2] Barr. Advisory Committee for Aeronautics. Permeability of Balloon Fabrics by Helium. 1915.

Edwards. U.S. Bureau of Standards. Tech. Paper 113. The Determination of Permeability of Balloon Fabrics. 1918.

[3] Dewar. Proc. Roy. Inst., pp. 813–[illegible]. 1918.

Work on the relative permeability of fabrics to helium and hydrogen has been carried out by Barr[1] who made careful measurements in 1915. The amount of helium at his disposal was limited, the total being about 310 ccs. The area of the test pieces used was 25 square centimetres; and measurements were made employing the volume-loss method.

Experiments on the permeability of fabrics to helium and to hydrogen have recently been carried out at the United States Bureau of Standards. While no account of this work has yet appeared in print, it is understood that the results obtained are in close agreement with those given in this paper.

For the present work the area of the test piece used was 500 square centimetres, and a supply of helium of practically 100 per cent purity was available.

DEFINITION OF PERMEABILITY

The British practice is to express permeability as the volume in litres of dry gas at 15·5°C. and 760 mm. which leaks through one square metre of fabric in 24 hours. Permeabilities are expressed in this paper according to this definition. Some experiments, however, express the volume in litres at 0°C. and 760 mm. In British practice the temperature of the fabric is usually 15·5°C.

The United States Bureau of Standards on the other hand, expresses permeabilities in litres of dry gas at 0° and 760 mm. passing through one square metre in 24 hours. The fabric is maintained at 25°C. during the period of test.[2]

The essential requirements for the determination of the leakage of a gas through a fabric are (*i*) an apparatus—usually called a permeameter—to hold a sheet of fabric so that air may be passed over one surface at a definite rate while the gas passes over the other surface, (*ii*) a means of determining the amount of this gas which diffuses through the fabric into the air.

In these tests a Shakespear permeameter was used and two methods were employed to determine the amount of gas in the air, (*i*) by using a Jamin Interferometer, (*ii*) by using a Katharometer. The permeameter is described below under "Description of Apparatus," while the use of the Interferometer and Katharometer is detailed under "Measurement of Permeability."

---

[1] Barr. *Loc. cit.*

[2] Tech. Paper. No. 113.

DESCRIPTION OF APPARATUS

The general arrangement of apparatus is shown diagrammatically in Fig. 1.

(a) *The Air Circuit*

The air stream maintained by means of a water pump and kept at a constant pressure by a blow-off, passed (*i*) through a flow meter which served to check the uniformity of the rate of flow, (*ii*) through a gas meter which measured the volume of air, (*iii*) through a drying train of calcium chloride and of sulphuric acid (*iv*) through a copper coil in a thermostat which ensured that the air was at the temperature of the fabric and then (*v*) through the air chamber of the permeameter. The outgoing air containing hydrogen or helium which had leaked through the fabric then passed (*i*) through a coil at air temperature, (*ii*) through a drying tube and then (*iii*) through a Jamin Interferometer or out into the air as desired.

(b) *The Gas Circuit*

The gas, helium or hydrogen, passed (*i*) through calcium chloride tubes and a sulphuric acid wash bottle, (*ii*) through a Shakespear Hydrogen Purity meter which indicated the purity, (*iii*) through a coil in the thermostat, (*iv*) through the upper chamber of the permeameter, (*v*) through calcium chloride and phosphorus pentoxide drying-tubes, (*vi*) through a chamber communicating with a Katharometer which indicated the purity of the gas and (*vii*) through a wash-bottle which served as a pressure regulator (*viii*) to the gas-outlet.

(c) *The Permeameter*

The permeameter, made to the design of Dr. G. A. Shakespear, was supplied by the Cambridge Scientific Instrument Co. Plate I shows the exterior with the Katharometer in position. It consists of two shallow circular drums, each about 26 cms. diameter and 1 cm. depth, with machined flanges 1·6 cms. wide. The volume of the air chamber is 500 cc. As will be seen from Plate II, the fabric is supported by concentric rings of metal which are notched so as to obtain uniform diffusion of gas or air throughout the chamber.

CONDITIONS OF TESTING

As permeability is dependent upon a number of factors, the conditions under which the tests in this paper were carried out are stated under the following headings:

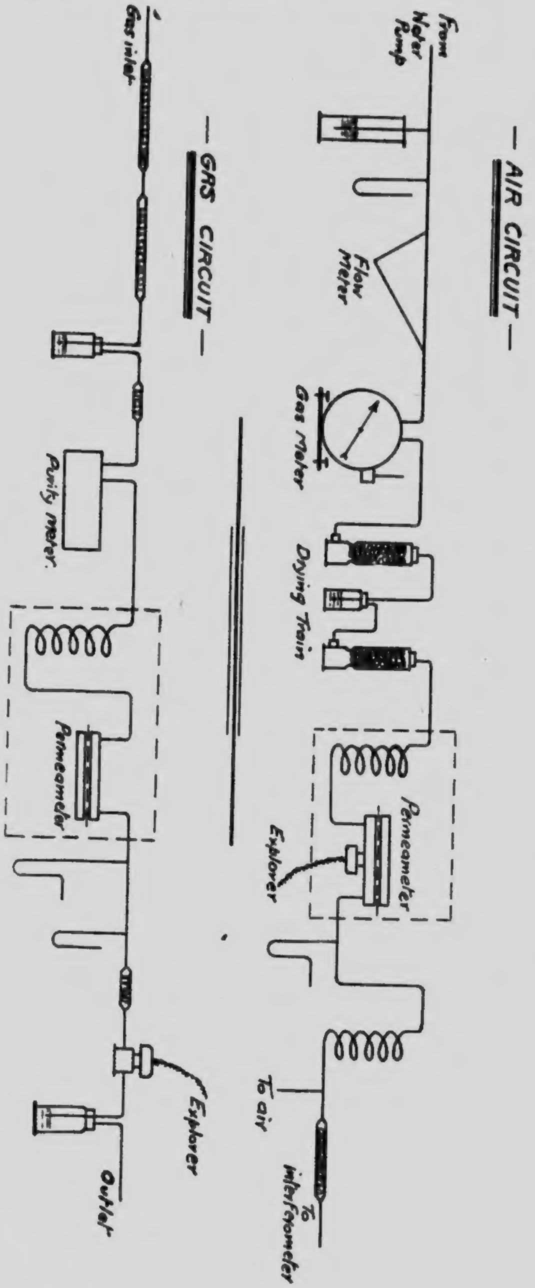

FIG. I

Diagrammatic Sketch of Apparatus

(a) *Purity of Gases*

In these experiments the hydrogen used was supplied by the British Oxygen Co., Ltd., and was guaranteed to contain less than 0·5% impurities (nitrogen and carbon monoxide). The helium, separated from natural gas by a liquefaction process, had been purified by a continuous-flow charcoal-absorption method[1] and was practically 100% pure.

(b) *Temperature Control*

As permeability has a considerable temperature coefficient, the permeameter and coils enclosed in dotted lines in Fig. 1 were placed in an electrically controlled thermostat maintained at a constant temperature (15·5°C. for the majority of the tests). The variation of the thermostat temperature was about 0·1°C. In some preliminary tests when the temperature was not at 15·5°C, the hydrogen permeability was corrected to the temperature of the helium permeability, using a temperature coefficient of 5%. This correction (for less than 1°C.) was applied to results IIA, IIIA, IVA, VA and VIA in Table III given below.

(c) *Rate of Air Flow*

The rate of air flow was varied from about 2 to 15 litres per hour according to the type of fabric under examination.

(d) *Pressure Control*

The gas and air drums of the permeameter were connected by a differential gauge and the pressure on the gas side controlled so as to give an excess gas pressure over air of about 3 cms. water. *Extreme* accuracy of control was not aimed at, but the pressure difference was substantially the same for the same fabric for hydrogen and for helium.

(e) *Time for Equilibrium*

After adjustment of the gas and air rates, readings of the gas outlet Katharometer were taken until it was ascertained that the gas chamber was completely filled with gas—except for the small amount of air leaking through the fabric. The diffusion of gas into the air chamber was followed by Katharometer observations. It was found that a period of an hour sufficed for equilibrium conditions to be established.

---

[1] Edwards and Elworthy. Proc. Roy. Soc. of Canada, 1919.

(*f*) *Fabrics*

The airship fabrics tested were supplied by the Department of Aircraft Production of the Admiralty, and are described in Table I (given below). Laboratory Reference Numbers are given in Column I of the Table.

The date of manufacture of the fabrics was not known.

The test-pieces were cut from the roll, choice being made of a portion of the fabric free from seams or apparent defects, and inserted in the permeameter without any preliminary drying or dessication.

TABLE I

Lab. No.	Description of Fabric	Approx. weight in grammes per square meter
I	2-ply, diagonal, rubber on inner face and between plies	140
VII	2-ply, diagonal, rubber between plies	230
II	2-ply, diagonal, rubber on inner face and between plies	330
III	2-ply, diagonal, rubber between plies, outer face aluminium	340
VI	2-ply, diagonal, rubber between plies, outer face aluminium	310
V	3-ply, inner diagonal to outers, rubber on inner face and between plies, outer face aluminium	450
IV	3-ply, parallel, rubber between plies, outer face aluminium	440
VIII	Single-ply, rubber on inner face, outer face one layer Goldbeaters' skin	85
IX	Single-ply, rubber on inner face, outer face 2 layers Goldbeaters' skin	85

MEASUREMENT OF PERMEABILITY

It has already been stated that two distinct methods were employed in these experiments to determine the amount of gas diffusing into the air through the sample of fabric.

(*a*) In the first method, the hydrogen or helium in the air was estimated by means of a Jamin interferometer, used in the manner described in another paper[1].

The general procedure adopted was (*i*) to establish the rates of flow of gas and of air, then, after an equilibrium condition in the permeameter had been attained, (*ii*) to take readings of the percentage of gas in the air at equal intervals of time over a period of about one hour. The rate of flow of air was given by a gas meter which was read at the beginning and end of the period. Intermediate readings were also taken to check the uniformity of the air flow.

---

[1] McLennan and Elworthy. Proc. Roy. Soc. of Canada, 1919.

These readings with the necessary temperature and pressure readings yield the following results:

V = the rate of flow of air expressed in litres per hour of dry gas at 15·5°C. and 760 mm.

r = the percentage of hydrogen or helium in the outflowing air.

If the area of the fabric exposed = A sq. cms. the permeability, P, is given by the equation

$$P = \frac{V \times r \times 10{,}000 \times 24}{100A}$$

In the permeameter employed A = 500 sq. cms. and, on substituting, the formula becomes $P = 4 \cdot 8 \times Vr$.

(*b*) In the second method, a Katharometer together with a mirror galvanometer was used. The Katharometer, manufactured by the Cambridge Scientific Instrument Co., Ltd., was designed by Dr. G. A. Shakespear and has been described by him elsewhere[1].

The explorer and galvanometer employed have been referred to in another paper[2].

In making Katharometer readings about 1 minute was allowed after adjustment. The permeameter air-chamber was then closed and readings taken at one minute intervals for about 20 minutes. When the readings were completed the exit-trap from the air-chamber of the permeameter was opened, and the air stream re-established. If subsequent readings were made, sufficient time was given for equilibrium conditions being reached.

With the Katharometer, the permeability (P) is given by the expression: P = galvanometer-scale divisions × a constant.

The constant for hydrogen-air was calculated from data supplied by the Cambridge Scientific Instrument Co., Ltd., while that for helium-air was deduced making use of the calibration results obtained by one of the writers.[3] The actual values of the constants found were for hydrogen 0·4377, and for helium, 0·6870.

RESULTS

The results obtained by the two methods are collected in tables II and III. Column 1 gives the fabric number as described in Table I; column 2, the sample mark; columns 3 and 4 the permeabilities to the nearest decimal place at 15·5°C. and 760 mm.; column 4, the thermostat temperature and column 5, the ratio of the helium to hydrogen permeability from permeabilities calculated to two decimal places.

---

[1] Shakespear. Advisory Committee for Aeronautics. No. 317. A new Permeability Tester for Balloon Fabrics. 1917.

[2] Murray. Proc. Roy. Soc. of Canada, 1919.

[3] Murray *loc. cit.*

The mean value of the ratio from Table II is 0·66, from Table III (omitting skin-lined fabrics) is 0·72. As the ratio with fabric 2 was abnormal, additional tests are being carried out on this fabric to ascertain the reason. For the two skin-lined fabrics the ratio is about unity. Additional tests of higher accuracy are also being made on these fabrics. Barr[1] concludes that the ratio for gold beaters' skin is about 1·5, with a footnote that this ratio may probably be more nearly equal to unity.

TABLE II

Interferometer Results

Lab. No.	Sample Mark	Permeabilities		Temp.°C	Ratio
		Hydrogen	Helium		
VII	A	9·4	6·1	15·5	0·65
II	B	8·4	6·5	15·5	0·77
III	B	7·5	5·0	15·5	0·67
VI	B	7·6	4·6	15·5	0·61
V	B	6·7	4·1	15·5	0·61
IV	B	5·5	3·5	15·5	0·64
					Mean 0·66

---

[1] Barr. *Loc. cit.*

TABLE III

Katharometer Results

Lab. No.	Sample Mark	Permeabilities		Temp. °C.	Ratio
		Hydrogen	Helium		
VII	A	10·0	7·1	15·5	0·71
II	A	9·2	7·6	15·9	0·83
	B	9·5	7·6	15·5	0·81
III	A	8·6	5·6	15·5	0·65
	B	7·4	4·9	15·5	0·66
VI	A	8·1	6·1	15·9	0·75
	B	7·3	4·9	15·5	0·68
V	A	6·0	4·8	14·5	0·80
	B	6·4	4·8	15·5	0·74
IV	A	4·7	3·2	14·6	0·69
	B	5·2	3·4	15·5	0·65
				Mean	0·72
VIII	A	2·4	2·5	15·5	1·02
	B	2.5	2·4	15·5	0·97
IX	A	0·13	0·17	15·5	1·27

SUMMARY

1. Tests have been carried out on the permeability to hydrogen and to helium of typical samples of fabrics.

2. With rubbered fabrics the permeability to helium has been found to be less than to hydrogen, the ratio of the helium to hydrogen permeability being (*i*) 0·66 by Interferometer method, (*ii*) 0·72 by Katharometer method.

3. With skin-lined fabrics the ratio of helium to hydrogen permeability was found to be about unity.

This investigation was carried out at the Admiralty Physical Laboratory under the direction of Professor J. C. McLennan, F.R.S., Scientific Adviser to the British Admiralty.

South Kensington,

14th April, 1919.

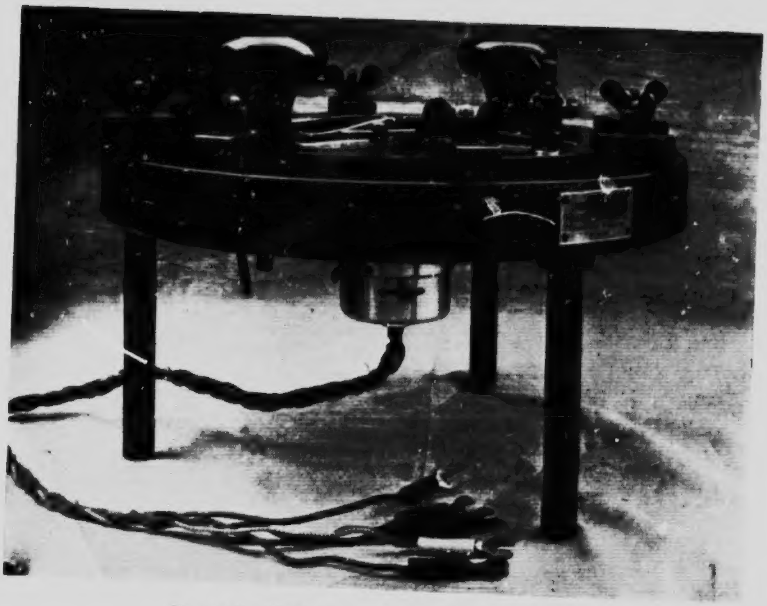

Plate I.—Shakespear Permeameter (closed)

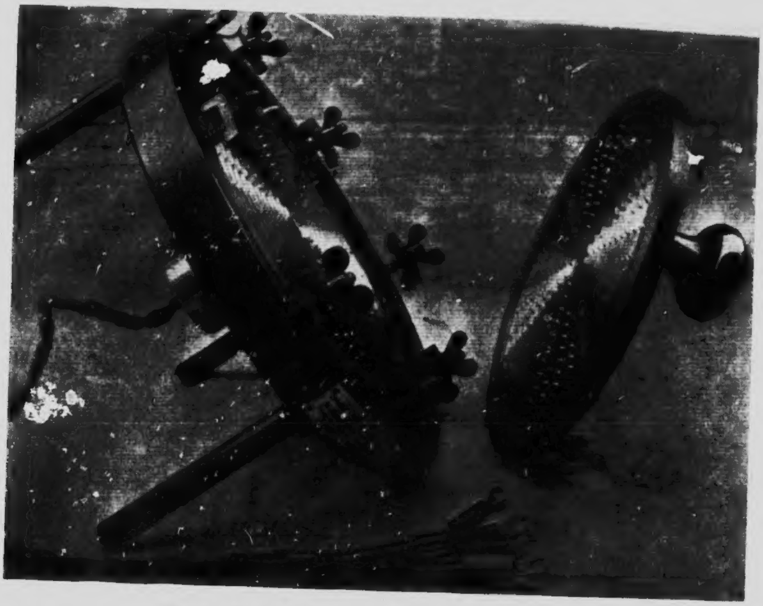

Plate II.—Shakespear Permeameter (open)

UNIVERSITY OF TORONTO STUDIES

Papers from the Physical Laboratories

The "Papers from the Physical Laboratories", issued as a special series of University of Toronto Studies, date from the year 1900. Nos. 1-17 were published by the Physical Department in a very limited edition and are no longer in print. For the sake of a complete record the numbering of the Papers, as forming a series of University of Toronto Studies, is made continuous with the earlier series and commences with No. 18. The earlier numbers are not now available either for sale or gift.

No. 41:	The intensity of the earth's penetrating radiation at different altitudes and a secondary radiation excited by it, by Professor J. C. McLennan and E. N. Macallum	0.25
No. 42:	On the relation between the adiabatic and isothermal Young's moduli of metals, by E. F. Burton	0.25
No. 43:	On the rotatory dispersion of quartz, by H. F. Dawes	0.25
No. 44:	On the mobilities of ions in gases at high pressures, by A. J. Dempster	0.25
No. 45:	Measurements of precision on the penetrating radiation from the earth, by Arthur Thomson	0.25
No. 46:	On the number of delta particles expelled concurrently with each alpha particle emitted by polonium, by W. T. Kennedy	0.25
No. 47:	On the mobilities of ions in air at high pressures, by Professor J. C. McLennan and David A. Keys	0.25
No. 48:	On the absorption spectra of mercury, cadmium, zinc, and other metallic vapours, by Professor J. C. McLennan and Evan Edwards	0.50
No. 49:	On the infra-red emission spectrum of the mercury arc, by Professor J. C. McLennan and Raymond C. Dearle	0.25
No. 50:	On the ionisation tracks of alpha rays in hydrogen, by Professor J. C. McLennan and H. N. Mercer	0.50
No. 51:	On the delta rays emitted by zinc when bombarded by alpha rays, by Professor J. C. McLennan and C. G. Found	0.25
No. 52:	On the ultra-violet spectrum of elementary silicon by Professor J. C. McLennan and Evan Edwards	0.25
No. 53:	On the ionisation potentials of magnesium and other metals, and on their absorption spectra, by Professor J. C. McLennan	0.25
No. 54:	On the Bunsen flame spectra of metallic vapours, by Professor J. C. McLennan and Andrew Thomson	0.25
No. 55:	On the ionisation of metallic vapours in flames, by Professor J. C. McLennan and David A. Keys	0.25
No. 56:	Emission and absorption in the infra-red spectrum of mercury, by Raymond C. Dearle	0.25
No. 57:	Some experiments on residual ionization, by K. H. Kingdon	0.25

No. 58:	Image formation by Crystalline media, by H. F. Dawes.	0.25
No. 59:	Periodic precipitation, by Miss A. W. Foster	0.25
No. 60:	Regularities in the spectra of lead and tin, by R. V. Zumstein	0.25
No. 61:	New lines in the extreme ultra-violet of certain metals, by D. S. Ainslie and D. S. Fuller	0.25
No. 62:	The absorption of helium by charcoal, by Stuart McLean	0.25
No. 63:	On the absorption spectra of thallium, aluminium, lead and tin, and arsenic, by J. C. McLennan, J. F. T. Young, and H. J. C. Ireton	0.25
No. 64:	On the optical transparency of certain specimens of fluorite, by J. F. T. Young and H. J. C. Ireton	0.25
No. 65:	The use of the Jamin Interferometer for the estimation of small amounts of helium or hydrogen in air, by J. C. McLennan and R. T. Elworthy	0.25
No. 66:	The estimation of the helium content of mixtures of gases by the use of a Katharometer, by V. F. Murray	0.25
No. 67:	The permeability of balloon fabrics to hydrogen and to helium, by R. T. Elworthy and V. F. Murray	0.25